

## APPLICATION FOR PATENT

Title: Compliant Swage

Inventors: John L. Baugh and Leopoldo S. Gomez

### PRIORITY INFORMATION

[0001] This application claims the benefit of U.S. Provisional Application No. 60/450,899 on February 28, 2003.

### FIELD OF THE INVENTION

[0002] The field of the invention is expansion of tubulars and more particularly the use of a compliant swage that can expand the tubular while compensating for tight spots where expansion cannot take place.

### BACKGROUND OF THE INVENTION

[0003] Tubulars are expanded for a variety of reasons. In one application a patch is expanded to repair cracked casing. In other applications tubulars or liners are expanded to connect to each other or to casing downhole to present a larger cross-sectional area for a segment of the well. In other applications, deformation or a collapse of casing from forces of the surrounding formation needs to be corrected to improve the borehole cross-sectional area in the affected zone.

[0004] Swages have been used to accomplish this task. Swages are generally a tapered shape coming to a fixed maximum diameter such that when pushed or pulled through the obstructed area results in making the tubular either resume its initial round dimension or expand the tubular into an even larger round dimension. More recently swages that could change circular dimension were disclosed by the inventors of the present invention in a U.S. provisional application filing on February 11, 2002 having serial number 60/356,061. That design allowed connected segments to move longitudinally with respect to each other to vary the circular maximum diameter of the

swage. This ability had the advantage of changing size in the face of an obstruction to avoid sticking the swage or overloading the swage driving apparatus. This device had the capability of reducing to a smaller diameter to allow clearing of an obstruction. Its limitation was that if a tight spot adjacent the outside of only a part of the circumference of the tubular to be expanded was encountered, the swage reduced its diameter symmetrically to clear the obstruction. This resulted in a decrease in cross-sectional area beyond the amount necessary to clear the localized obstruction.

**[0005]** The present invention presents a compliant swage that has enough range of motion among its components to provide sufficient articulation to let the swage go out of round in profile. This permits a part of the swage to reduce in dimension at the localized obstruction while in the remaining regions where there is no such resistance, the expansion can continue as the swage advances. The net result is a larger cross-sectional area can be obtained than with the prior design and the obstruction can still be cleared. These and other advantages of the present invention will become more apparent to those skilled in the art from a review of the description of the preferred embodiment and the claims, which appear below.

#### SUMMARY OF THE INVENTION

**[0006]** A compliant swage has the ability to change shape to allow clearance of an obstruction while permitting expansion to go on in other areas removed from the obstruction. A series of segments move with respect to each other longitudinally to change overall size. The segments have an additional degree of freedom to change from a round profile of varying diameter to an oblong, elliptical, or an irregular shape so as to compensate in the portion that encounters an obstruction to let the swage pass while at the same time permitting the intended maximum expansion in other portions where conditions permit such expansion.

#### DETAILED DESCRIPTION OF THE DRAWINGS

**[0007]** Figure 1 is a section view of the swage assembly in the run in position;

**[0008]** Figure 2 is the view of figure 1 in the beginning to swage position;

[0009] Figure 3 is a detail of a pair of segments that are upwardly oriented and an adjacent pair that is oppositely oriented;

[0010] Figure 4 is a section view through lines 2-2 of Figure 2;

[0011] Figure 5 is the view of Figure 2 showing the expansion proceeding prior to encountering an obstruction;

[0012] Figure 6 is the view of Figure 5 just as an obstruction is about to be encountered;

[0013] Figure 7 is a section view along lines 7-7 of Figure 2 when an obstruction is encountered;

[0014] Figure 8 is a perspective view of two adjacent segments showing how they connect to each other in a tongue and groove manner;

[0015] Figure 9 is the view from the opposite end as compared to Figure 8;

[0016] Figure 10 is a perspective view of the assembled segments in the maximum dimension position;

[0017] Figure 11 is the view of Figure 10 in the minimum dimension position during run in;

[0018] Figure 12 shows an alternative embodiment where the segments abut in arcuate contact and the segments are in a round configuration;

[0019] Figure 13 is the view of Figure 12 after an obstruction is encountered and the segments have moved to an out of round shape to clear the obstruction;

[0020] Figure 14 is an alternate embodiment to Figure 3 where a single segment is connected at the T-shaped connection instead of a pair of segments; and

[0021] Figure 15 is the mating segment to Figure 14 in the alternative embodiment to Figure 12 where the segments have arcuate edge contact and a single segment rather than a pair is connected at a T-shaped connection.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0022] Figure 1 shows the preferred embodiment of the swage apparatus **A** of the present invention. It has a mandrel **10** with thread **12** for connecting tubing or some other driving mechanism (not shown). Passage **14** has lateral exits **16** and **18** to communicate applied pressure to annular cavities **20** and **22** respectively. Rounding piston **24** is sealed by seals **26** and **28** so that pressure in cavity **20** urges rounding piston **24** toward lower end **30** of the apparatus **A**. Swage anchor **32** is held at thread **34** to mandrel **10**. Near its lower end **36** there are a plurality of preferably T-shaped openings **38**, although other shapes can be used.

[0023] Referring to Figure 3 swage segments **40** and **42** have C-shaped upper ends **44** and **46** respectively so that when brought together the adjacent upper ends **44** and **46** take on a T-shape that is designed to fit loosely in T-shaped openings **38** in swage anchor **32**. Referring to Figures 1 and 9, it can be seen that upper ends **44** and **46** respectively include beveled surfaces **48** and **50** onto which the beveled lower end **52** of swage anchor **32** is brought to bear.

[0024] The assembly that comprises the compliant swage **54** is partially shown in a flattened view in Figure 3 and in perspective in Figure 11, during the run in procedure.

[0025] Figure 11 shows a pattern of pairs of segments **40** and **42** that are attached to swage anchor **32** interspersed with segment pairs **56** and **58** that are attached below to the fixed diameter swage **60** through generally T-shaped openings **62**. Openings **62** are the mirror image of openings **38** and serve a similar function. Referring to Figure 1, the optional swage **60** is biased by preload piston **64**. Seals **66** and **68** seal piston **64** in cavity **22** so that pressure through passage **18** drives piston **64** and segment pairs **56** and **58** in an uphole direction toward thread **12**. That same pressure in passage **14** drives the rounding piston **24** downhole toward lower end **30** and into beveled surfaces **48** and **50** of each

segment pair 40 and 42. Force to move the rounding piston 24 may be provided by mechanical springs or other means. Rounding piston 24, in the absence of an irregular obstruction downhole, forces the segments 40, 42, 56 and 58 into a circular shape shown in Figure 4, due to the contact between beveled surface 52 with its corresponding beveled surfaces 48 and 50 on segment pairs 40 and 42. The swage 60 is optional and piston 64 can bear directly on segment pairs 56 and 58, without departing from the invention. Alternatively, the bias provided hydraulically by piston 64 can be provided by other means such as mechanically by a spring or a stack of Belleville washers, for some examples. In some configurations all the required preload will be provided by the fixed swage 60.

[0026] Figure 1 illustrates a run in position with preferably no pressure in passage 14. In that case there is no uphole pressure from piston 64 and segment pairs 56 and 58 are in their lowermost position so that the compliant swage assembly is at its minimum dimension. This position is best seen in the perspective view of Figure 11. Ridgelines 70 and 72 on segment pairs 56 and 58 are longitudinally offset from ridgelines 74 and 76 on segment pairs 40 and 42. This should be compared with the swaging position shown in Figure 10. In this view, fluid pressure is applied in passage 14 pushing piston 64 uphole and with it segment pairs 56 and 58. The ridgelines 70, 72, 74 and 76 align in a circular configuration, as shown in Figure 4. The circular configuration is promoted by the wedging action from beveled lower end 52 of rounding piston 24 forcing the segment pairs 40 and 42 into such a shape. Since all the segment pairs are interconnected, as will be described, the compliant swage assembly 54 as a whole assumes a circular shape for the purpose of swaging at the pre-designated maximum dimension, illustrated in the perspective view of Figure 10.

[0027] Figure 4 shows a mode of interconnection. Every segment preferably has a tongue 78 on one edge and a groove 80 on the opposite edge. On either side of each tongue 78 are surfaces 82 and 84. On either side of groove 80 are surfaces 86 and 88. Surfaces 84 and 88 define a gap 90 between them and surfaces 82 and 86 define a gap 92 between them. These gaps allow articulation between adjacent segments so that the circular shape shown in Figure 4 for swaging at maximum dimension uniformly until an

exterior obstruction is met can change into an out of round shape shown in Figure 7. To assume the shape of Figure 7, some of the gaps 90 have closed completely while gaps 92 between the same two segments have opened fully in zones 94 and 96. At the same time, in zones 98 and 100 the movement is opposite. The compliant swage assembly 54 has now taken a somewhat oval shape in departing from the optimal round shape. It should be noted that depending on the allowable dimensions of gaps 90 and 92 a greater or lesser amount of articulation is possible. There are several limiting factors on the amount of articulation provided. One is the strength of the connection between a tongue 78 and an adjacent groove 80. Another, is the desire to keep the outer gaps 92 to a minimum dimension for the reason that large gaps can allow opposed edges such as 102 and 104 to concentrate stress in the expanded tubular by putting line scores in it. Depending on the amount of expansion and subsequent service, such scoring and stress concentration can result in premature cracking of the expanded tubular. Figures 4 and 7 illustrate that the articulated swage assembly 54 is held together at maximum dimension of Figure 4 or in an out of round articulated shape to allow the expansion of the tubular to the maximum dimension where no resistance is encountered while allowing inward articulation to clear the obstruction in the zone where it is encountered. The net result is a larger expanded cross-section of the tubular where the obstruction occurs than would have been possible with the prior design that simply transitioned from a larger circle to a sufficiently smaller circle to clear the exterior obstruction. Another limiting issue on the amount of articulation is the tubular being expanded. There are limits that the tubular can endure in differential expansion between its various zones to clear an obstruction. The design of Figures 4 and 7 represent one solution to the need to hold the segments together while permitting articulation to achieve a desired swaging shape change. Clearly the tongue and groove connections hold the assembly of segments together as they are moved from the run in position of Figure 1 to the onset of swaging position shown in Figure 2 with pressure applied to passage 14.

**[0028]** Figures 12,13,14 and 15 show an alternate design. The segments are no longer in pairs as shown in Figure 3; rather a segment 110 has a T-shaped connection 108 to be inserted into an opening 38 in swage anchor 32. Abutting on either side is a segment 106 that is oppositely oriented and connected to swage 60. The interface between the

segments 106 and 110 is no longer a tongue and groove. Rather, each interface is a pair of arcuate surfaces 112 and 114 to allow the assembly articulate from the originally round shape shown in Figure 12 to an out of round shape shown in Figure 13 to clear an obstruction external to the tubular being expanded. The end connections of the segments 106 and 110 respectively to swage anchor 32 and swage 60 are made deliberately loose to permit relative movement between surfaces 112 and 114 to permit the articulation to the desired shape to avoid the obstruction exterior to the tubular being swaged. One notable difference is that there are no gaps in the periphery 116 where the swaging action is taking place regardless of the configuration of the segments in the round or out of round positions shown in Figures 12 and 13. Those skilled in the art will appreciate that band springs or equivalents can be used to limit the outward movement of the segments 106 and 110 as the interacting arcuate surfaces 112 and 114 do not provide such an outward travel stop. Even using the interface of Figures 12 and 13, the minimum and maximum dimensions of the compliant swage assembly 54 shown in Figures 1 and 2 are still achieved by relative longitudinal movement between the segments oriented uphole and those that are oppositely oriented. The total number of segments is fewer in the Figures 12,13,14 and 15 version but greater numbers of segments can also be used. For example, segment pairs as shown in Figure 3 can be used with the arcuate edge interfaces, within the scope of the invention. Conversely, as shown in Figure 14 the segment pairs of Figure 3 can be cut in half using larger segments that still employ an edge connection using a tongue and groove or another mechanically equivalent arrangement.

**[0029]** The method of using any of the above-described configurations can be seen by initially looking at Figure 1 for the run in position. At this time there is no pressure applied in passage 14 and the piston 64 and with it the swage 60 and the connected segments, such as 56 and 58 are in their lowermost position, simply due to their own weight. The compliant swage assembly 54 is in the Figure 11 position with ridgelines 70 and 72 out of alignment with ridgelines 74 and 76. The compliant swage 54 is therefore in its minimum diameter position. Those skilled in the art will realize that the expansion can occur along the aligned ridge lines, as shown in Figure 10 or along a surface as opposed to a line contact shown in Figure 10. The Figure 10 position is achieved by putting pressure from the surface in passage 14 to push swage 60 uphole and

to force rounding piston 24 down on beveled surfaces 48 and 50. This latter action puts the compliant swage in a round configuration illustrated in Figure 4 for the start of swaging. This position of the apparatus A is shown in Figure 2. If used, the fixed swage 60 enters the tubing to be expanded first. If it will not pass, the apparatus A must be retrieved. Once it passes, the compliant swage assembly 54, now in the Figure 10 position due to pressure in passage 14, makes contact with the tubular to be expanded. The segments remain in the round position shown in Figure 4 as long as there is no external obstruction to expansion of the tubular, as is shown in Figure 5. When a restriction or obstruction is reached, as shown in Figure 6, the compliant swage assembly 54 will articulate to change dimension to try to pass the obstruction by getting smaller in the zone where the obstruction is found and swaging as large as possible where the obstruction is not present. This articulation occurs with pressure continuing to be applied in passage 14. If the tongue 78 of one segment is engaged to a groove 80 in an adjacent segment, relative rotation about an axis defined by the tongue in groove connection permits the articulation as the size of gaps 90 and 92 between the affected segment pairs begins to change. In the abutting arcuate surfaces design shown in two positions in Figures 12 and 13, relative rotations along the arcuate surfaces 112 and 114 results in the desired articulation while presenting a continuous and uninterrupted surface or edge 116 for continued swaging despite an obstruction. In the end, if the compliant swage assembly 54 can actually pass through the obstruction, the resulting cross-sectional area of the expanded tubular is larger than it otherwise would have been if its circular cross-section had been maintained but its dimension reduced to the point where the obstruction could have been cleared. Clearly the larger the number of segments in the compliant swage assembly 54 the better its ability to articulate. However, the maximum round diameter of the compliant swage assembly 54 and the required strength of the segments to actually do the swaging required will have an effect on the number of segments to be employed.

[0030] Those skilled in the art will appreciate that surfaces 112 and 114 do not have to be singular arcs or have the same radius. They can be a series of surfaces and have different curvatures. The illustrated embodiment is illustrative of the inventive concept of articulation in combination with nearly continuous edge or surface contact.

The alternative articulation concept is also illustrative of the ability to articulate but allowing some gaps in the swaging line or surface contact to accomplish the desired articulation.

**[0031]** The foregoing disclosure and description of the invention are illustrative and explanatory thereof, and various changes in the size, shape and materials, as well as in the details of the illustrated construction, may be made without departing from the spirit of the invention.